

The role of analysis in the development of rotor ice protection systems

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Areas Requiring Protection

- Engines & Intakes
- Rotor Systems
- Other Aerodynamic Surfaces
- Windscreens
- Aerials
- Sensors
- Weapon Systems

Rotor Systems = Greatest Challenge

Rotor Ice Protection Systems - Required Attributes

- Effective
- Minimum Power
- Reliable
- Affordable

Favoured option: Electrothermal de-icing

Design Considerations

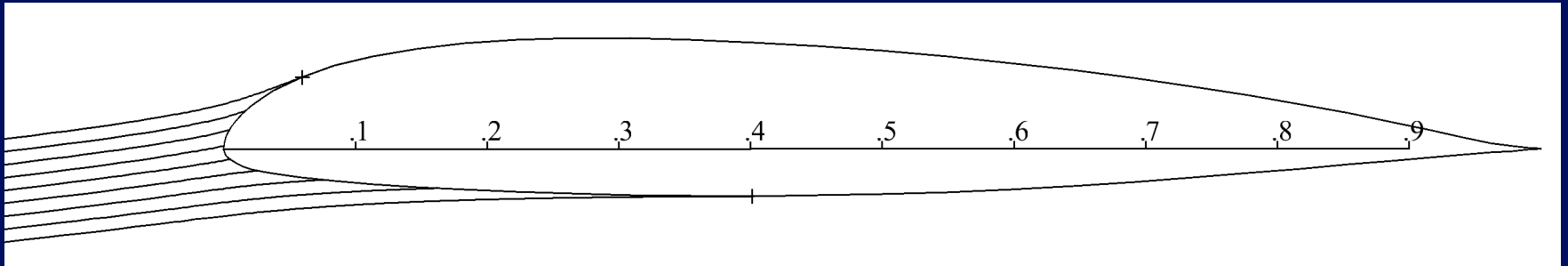
- Rate and form of ice accretion
- Chordwise and spanwise extent of heating
- Power intensity distribution
- Control of heated areas: on-times, off-times
- Integration of heaters into blade structure
- Integration of tail rotor protection into overall system

Rotor ice accretion prediction

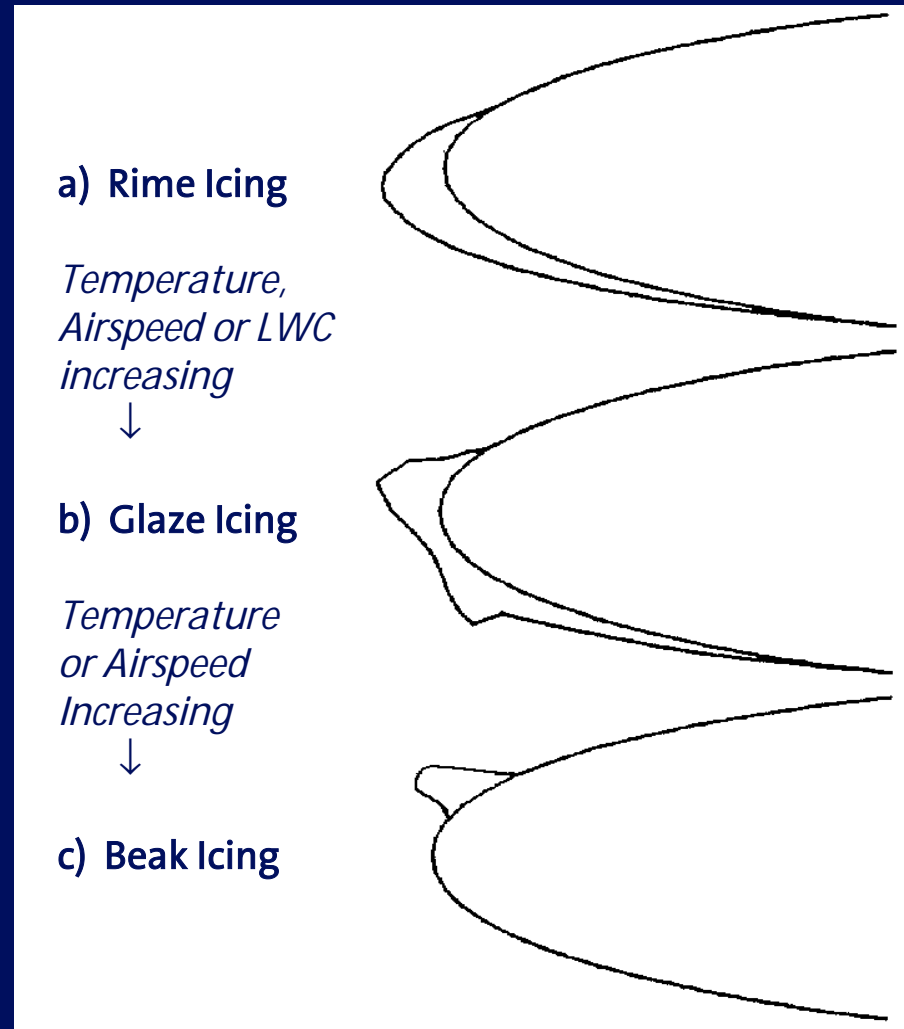
Modelling of Rotor Blade Ice Accretion

- Two stages:
 - Water Impingement
 - Ice Accretion
- Function of many variables, e.g.
 - Aerofoil size & section
 - Local velocity and incidence
 - Atmospheric conditions e.g. OAT, LWC
- QinetiQ Icing Codes
 - TRAJICE2 - steady state, 2D
 - CYBLACC - cyclic variation of local velocity and incidence

Impinging Droplet Trajectories



Variation of Ice Shape with Conditions

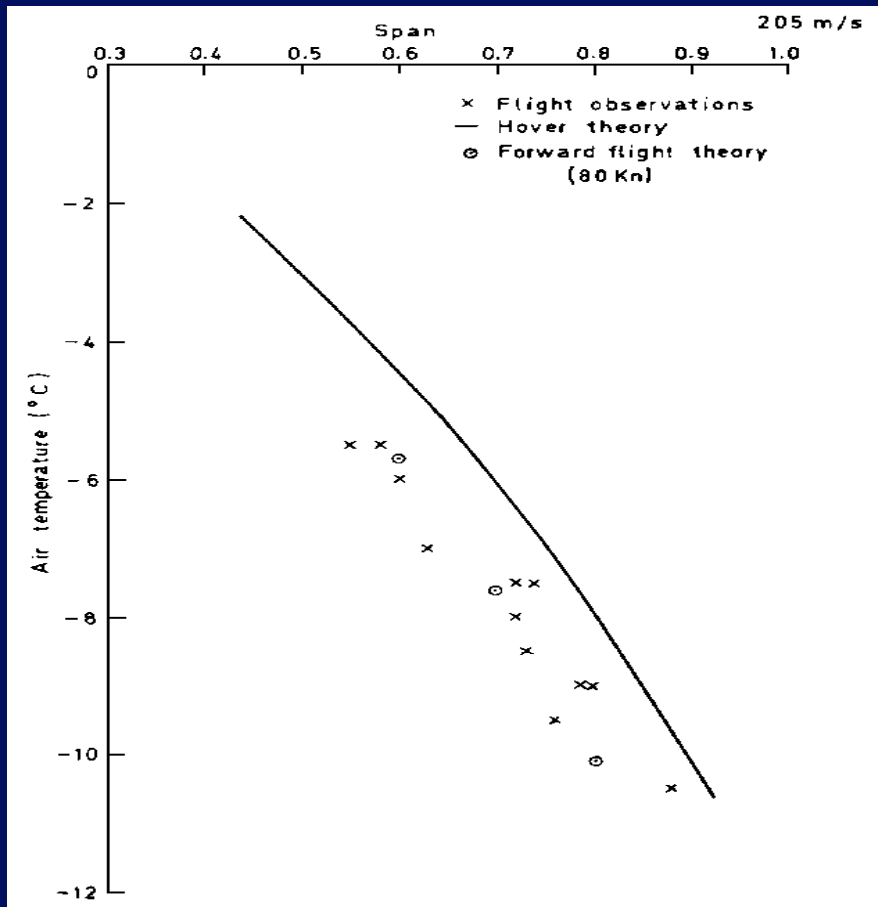


Ice Formation on EH101 Main Rotor Blade in Flight

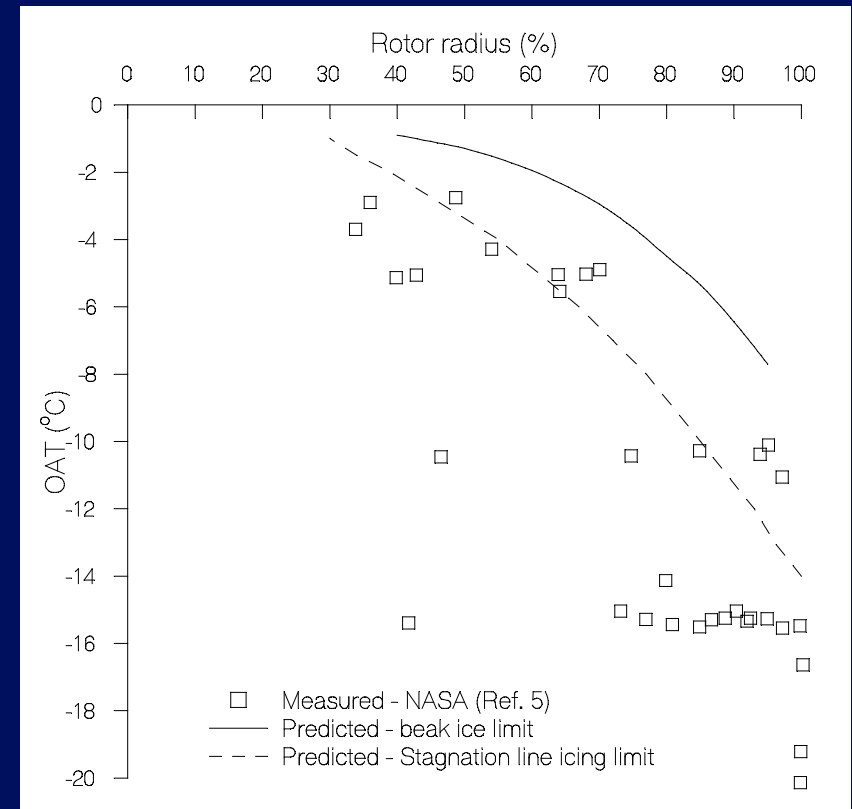


Icing Threshold on Stagnation Line of Rotor Blade

Wessex, main rotor

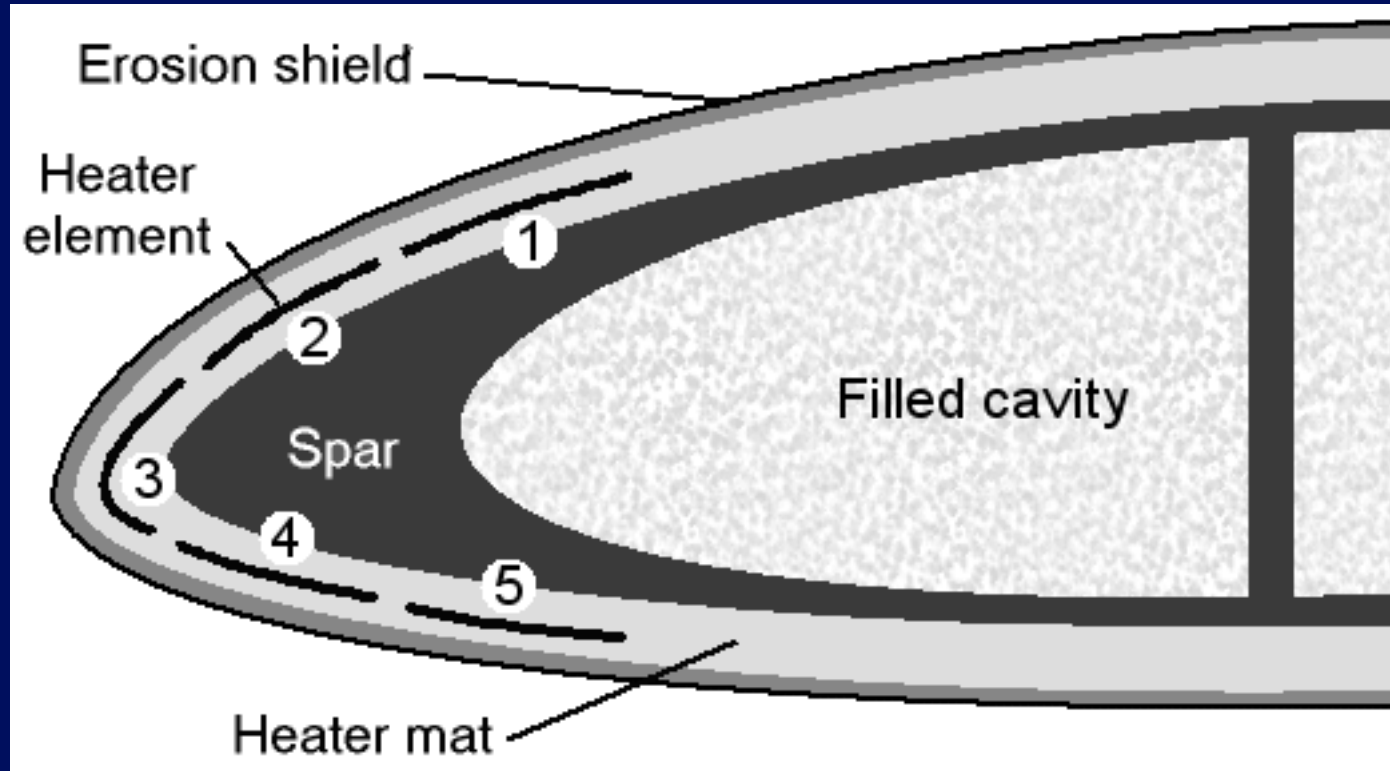


Model rotor

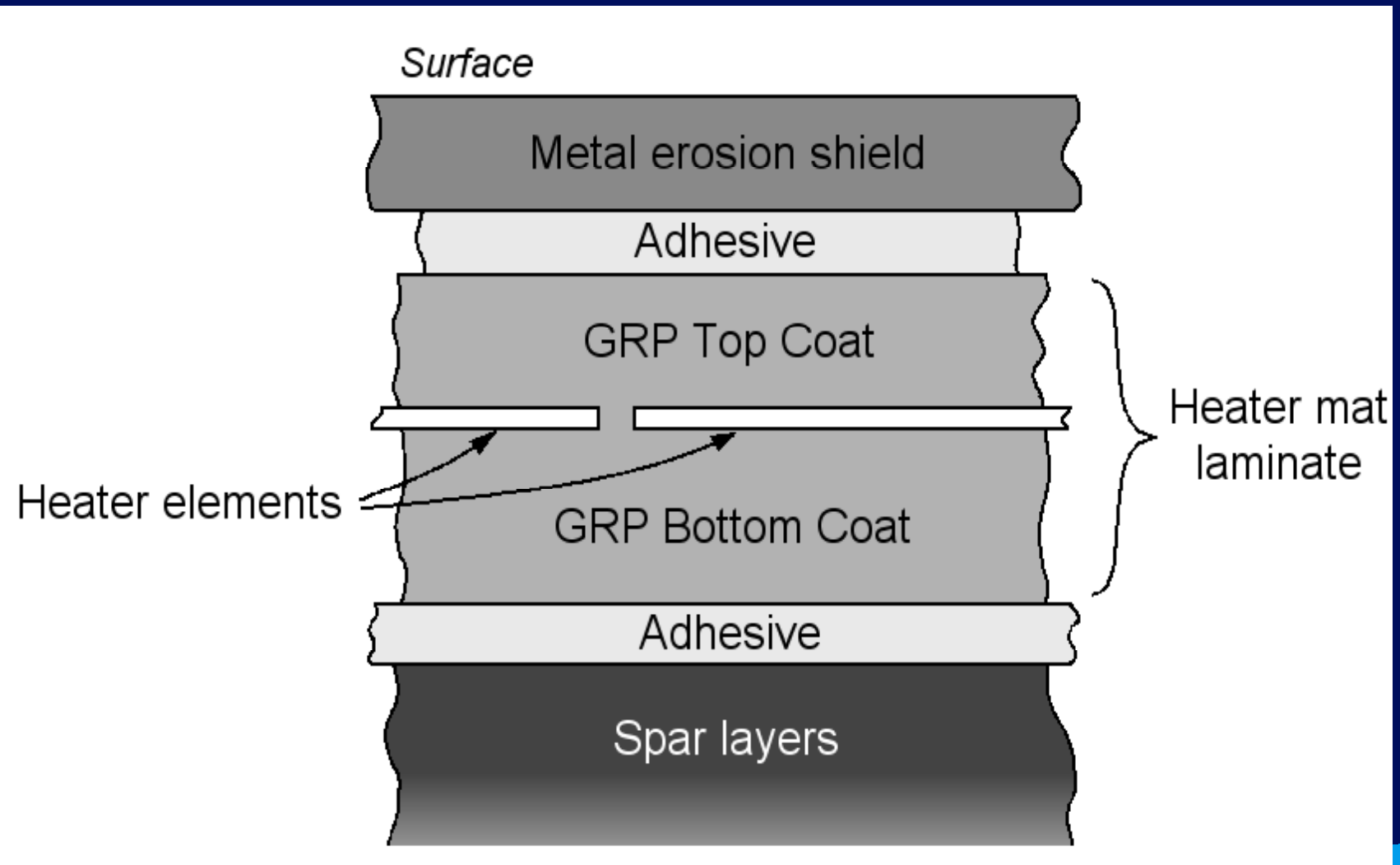


Rotor ice protection systems

Typical Layout of Rotor Blade De-icing System

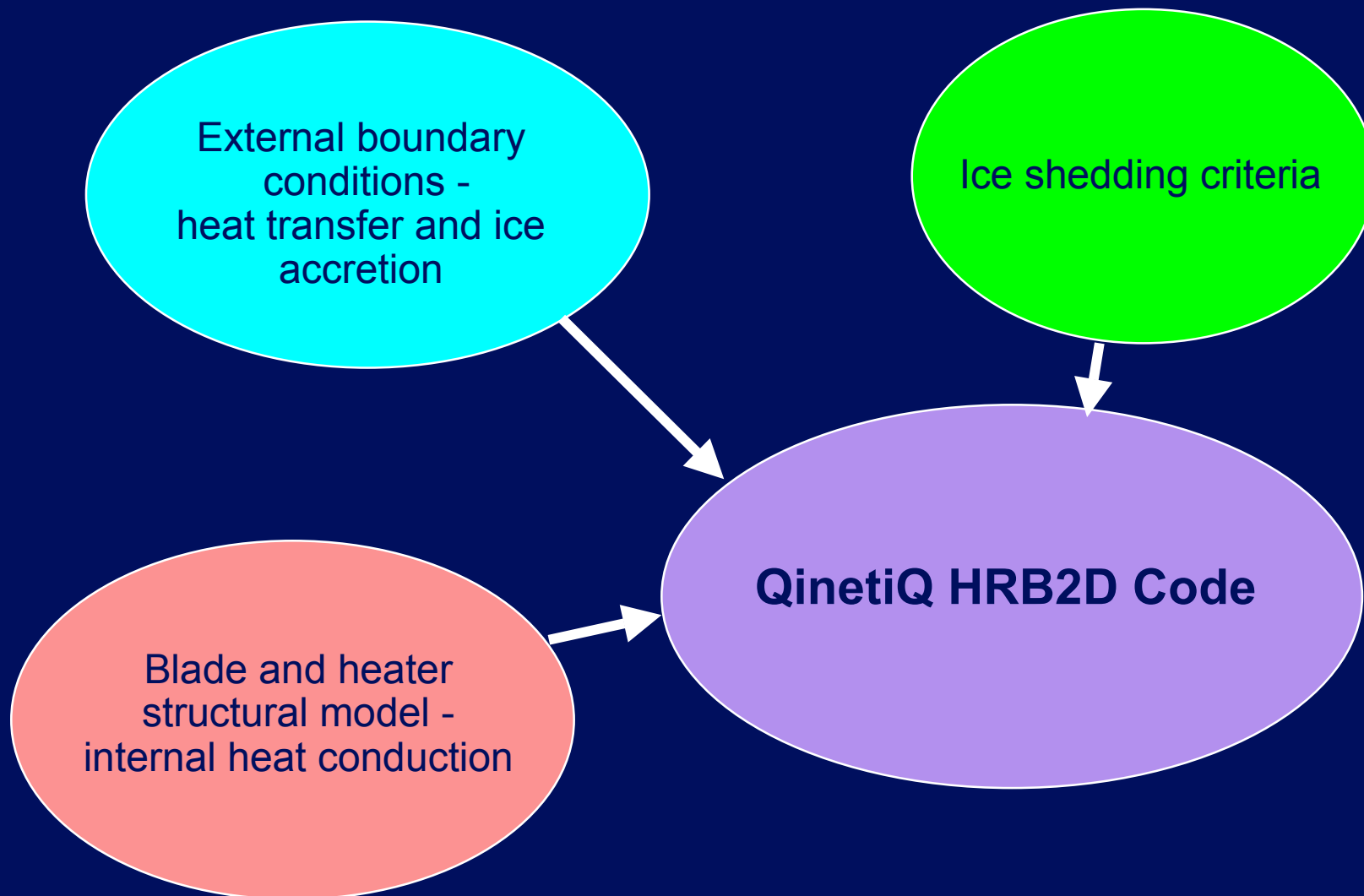


Cross-section of Heater Mat and Blade Spar

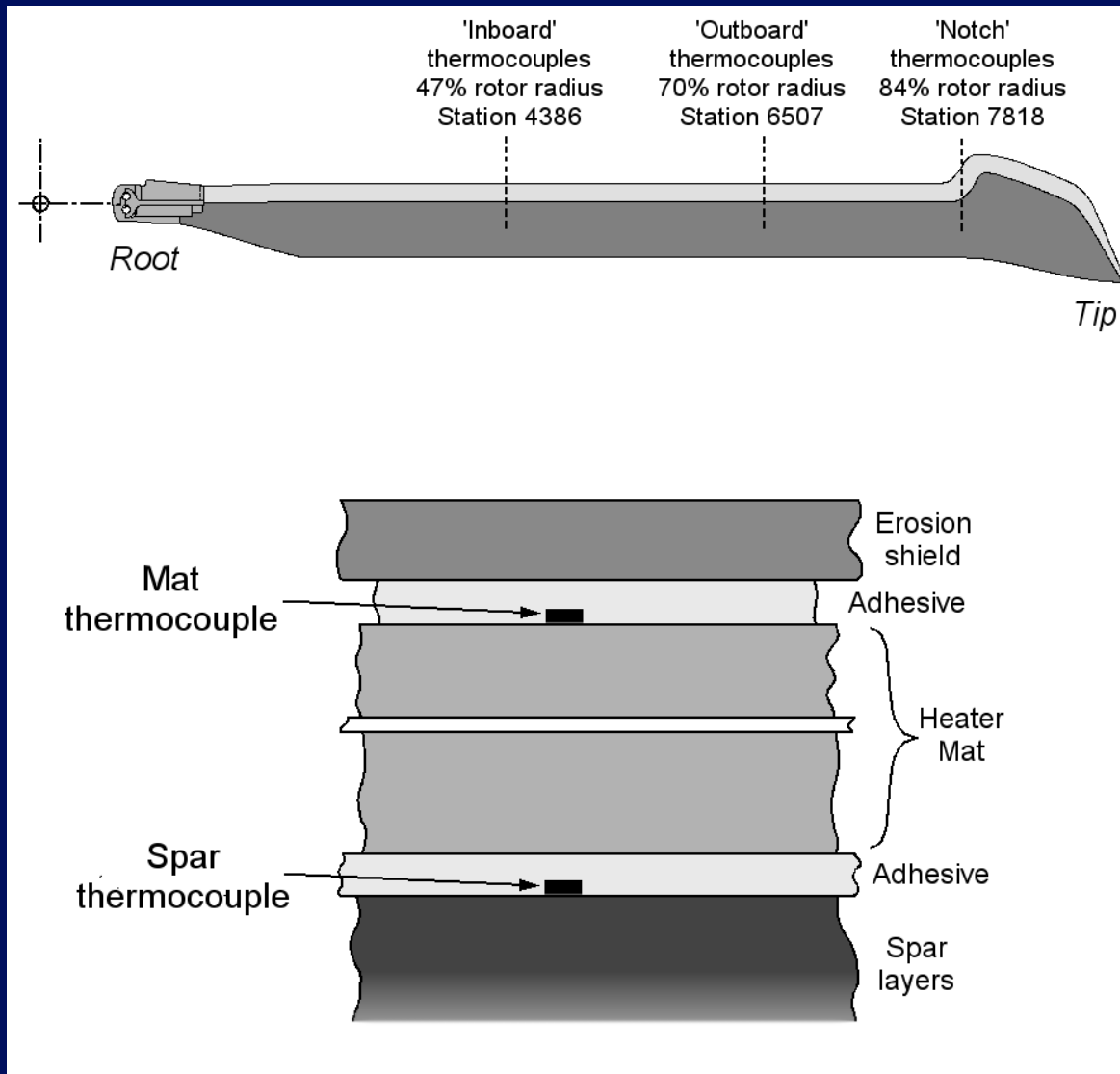




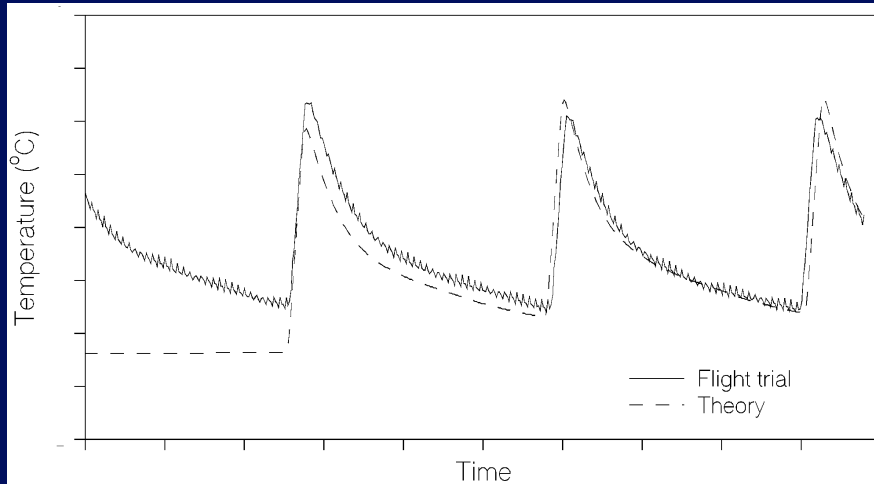
Modelling of Electrothermal De-icing System



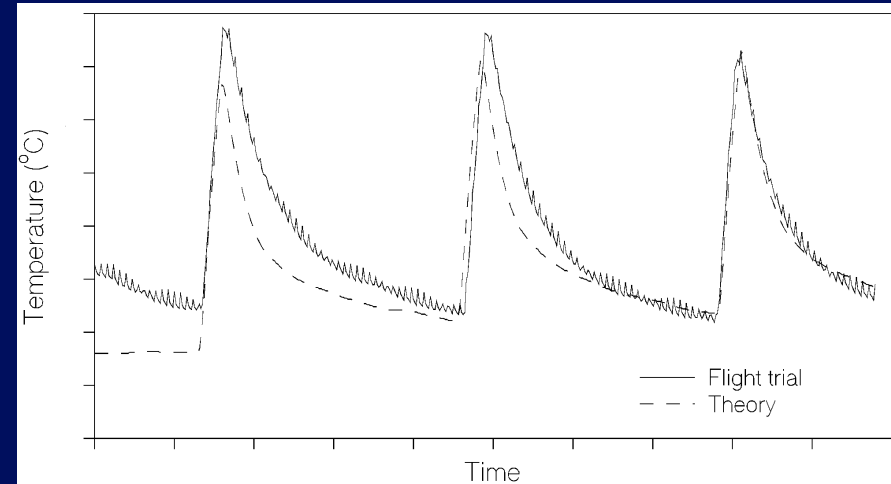
Location of Thermocouples in EH101 Rotor Blade



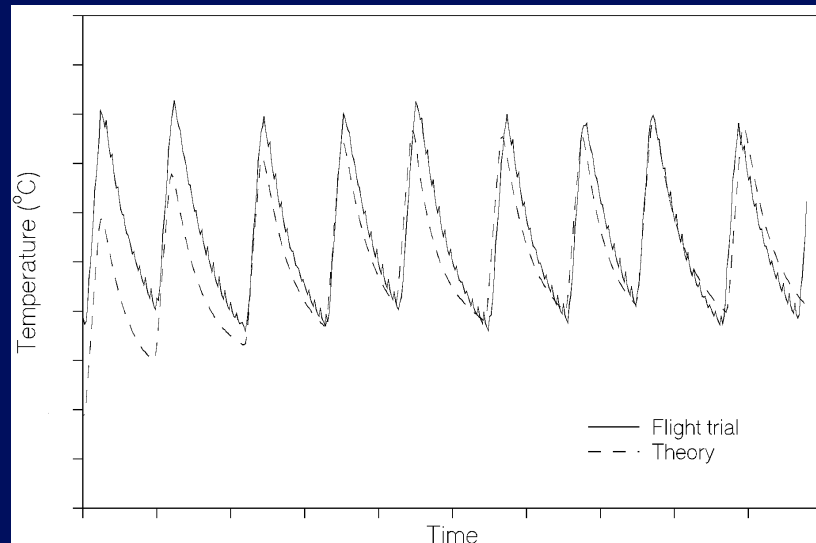
Temperature-Time History, 70% Span



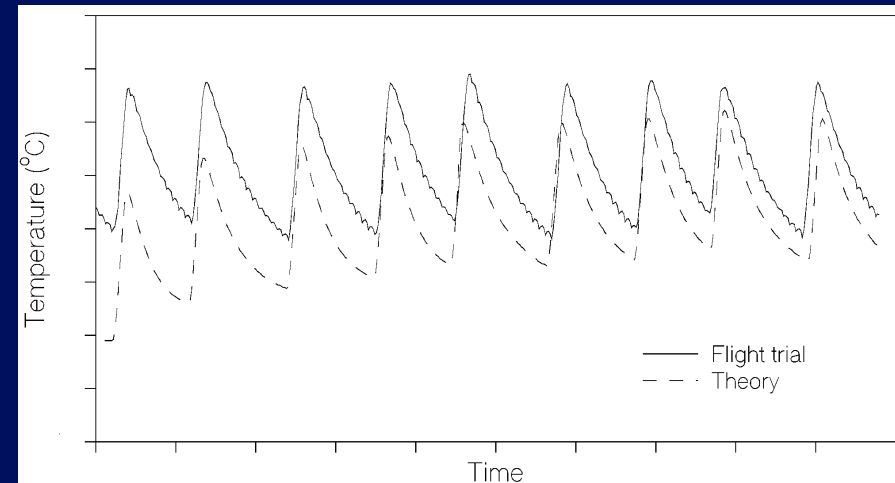
Element 1



Element 2

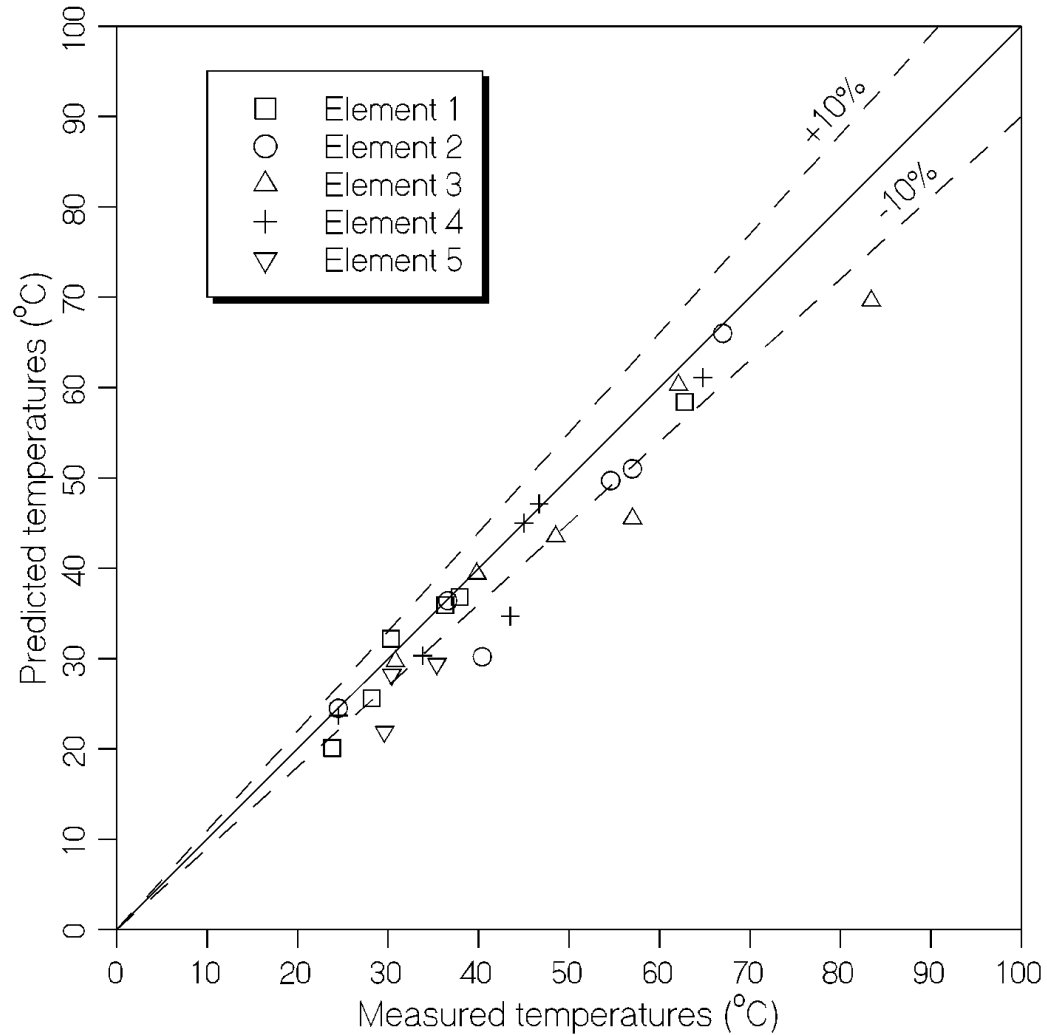


Element 3



Element 4

Peak Temperature Comparison

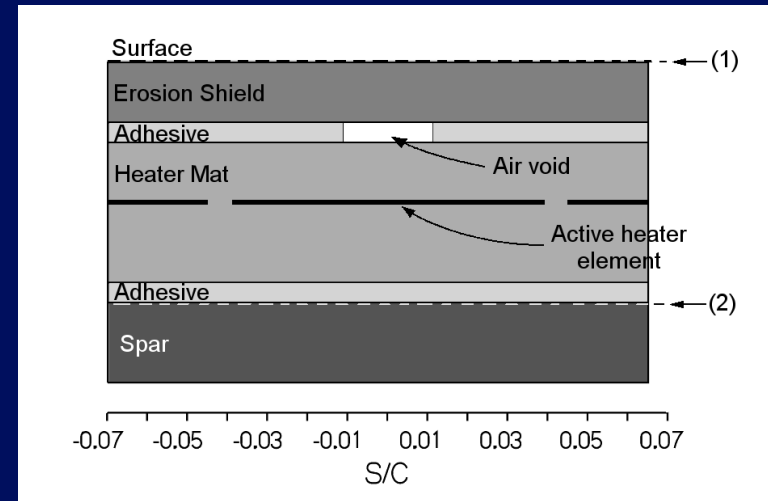
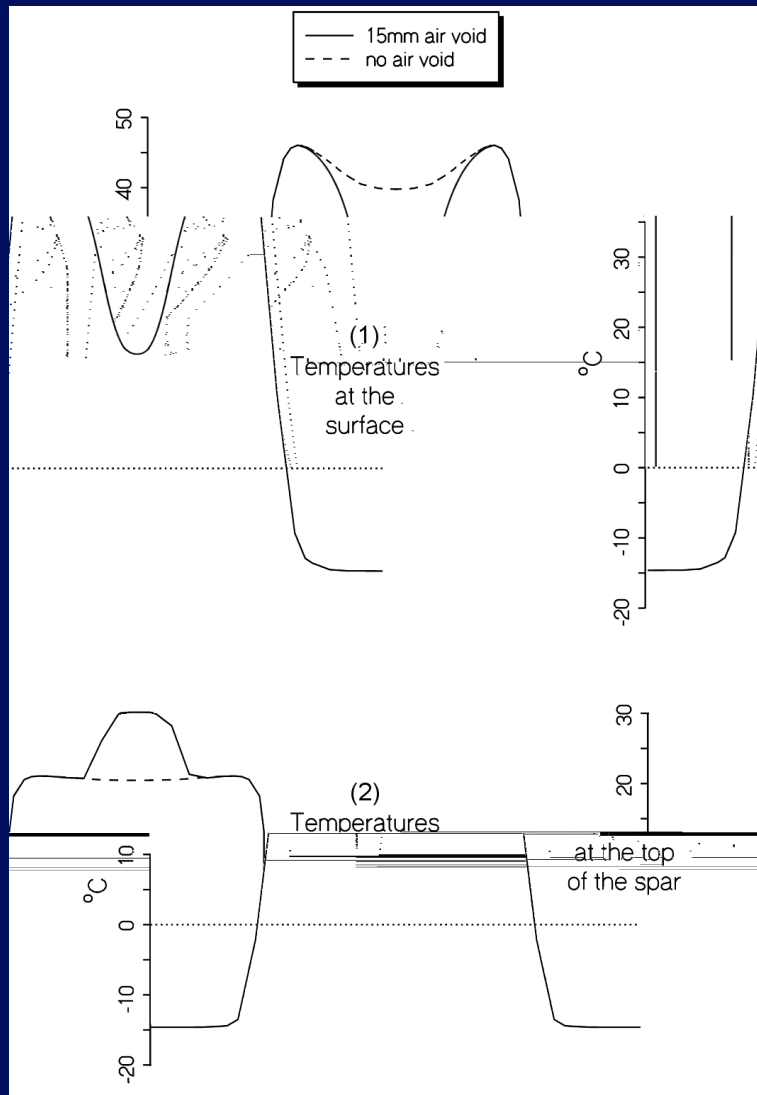


Model Application to Manufacturing Variability & Fault Conditions

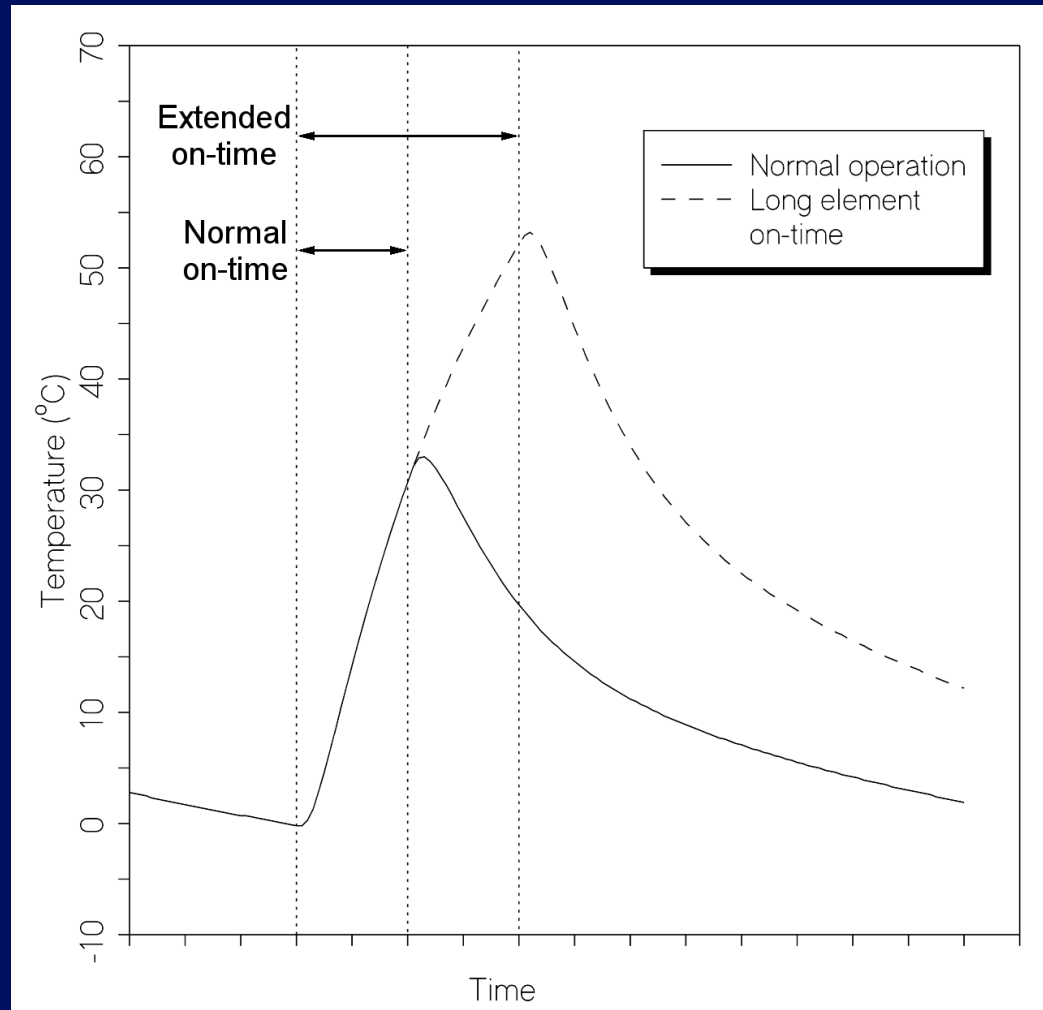
The HRB2D model may be used to assess the following:

- Manufacturing variability of heater mat power intensity
- Manufacturing tolerance in blade build, e.g. in adhesive layer thickness
- Voids in manufacture or delamination / de-bonding in service e.g. between erosion shield and heater mat
- Faults in controller operation
 - failure to heat a mat within a sequence
 - extended energisation of a particular mat

Effect of Air Void on Internal Temperatures



Effect of Extended On-Time on Blade Temperature



Performance degradation

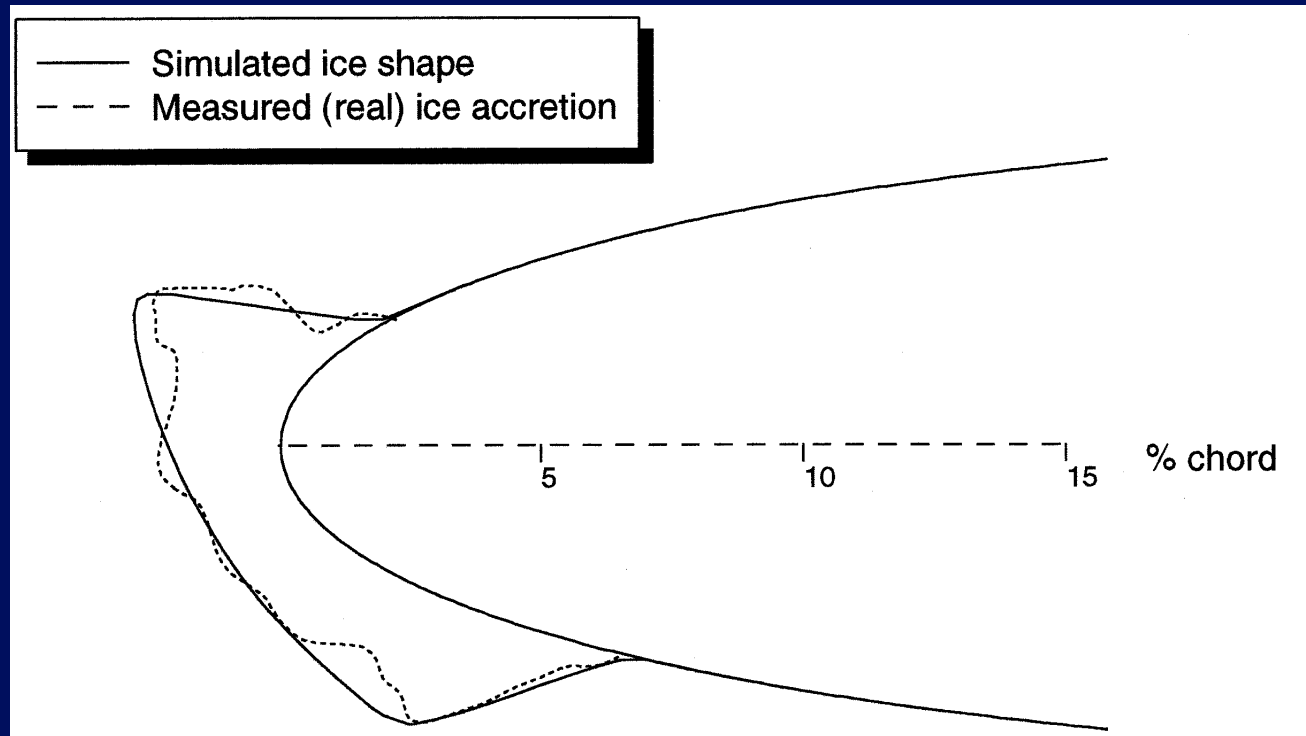
Icing effects on rotor performance

- Ice protection system is required to avoid:
 - Large torque (power) increase
 - Premature stall
 - Trim changes
 - Increased vibration

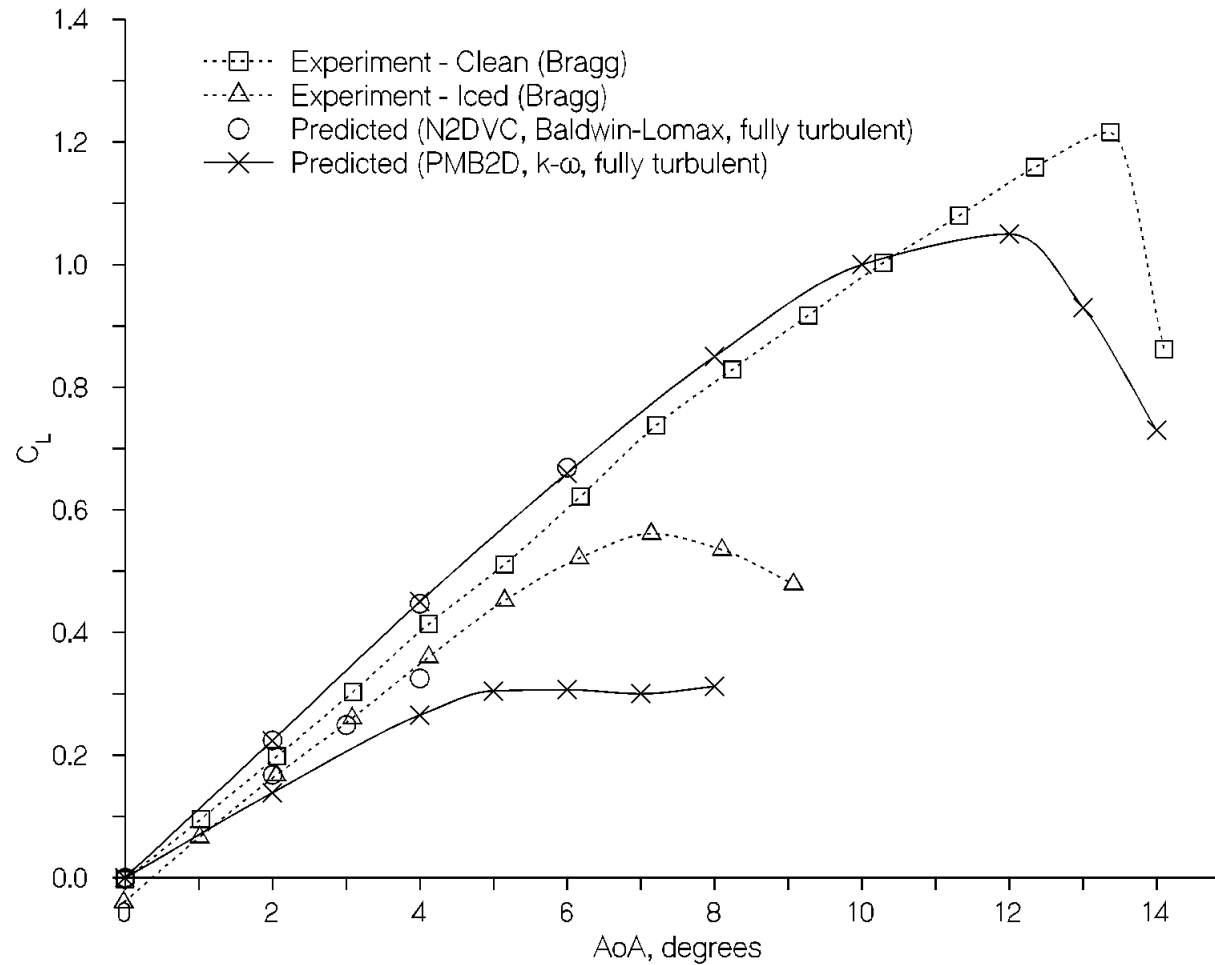
Icing effects on performance

- Can model as:
 - Aerofoil problem (2D)
 - Whole vehicle problem (rotors and fuselage)

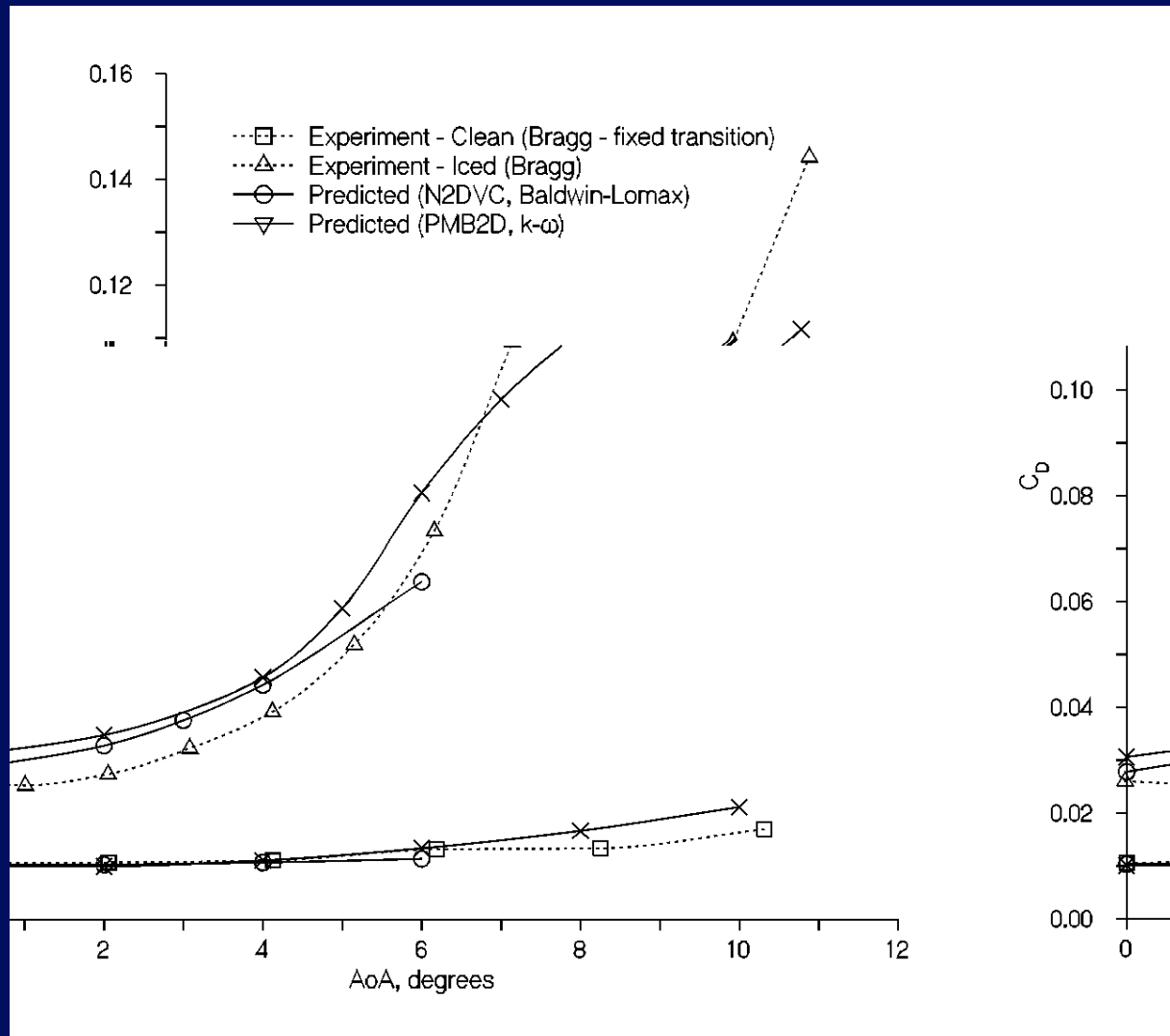
Simulated Ice Shape for CFD Modelling



Predicted Lift using two Navier-Stokes Codes



Predicted Drag using two Navier-Stokes Codes

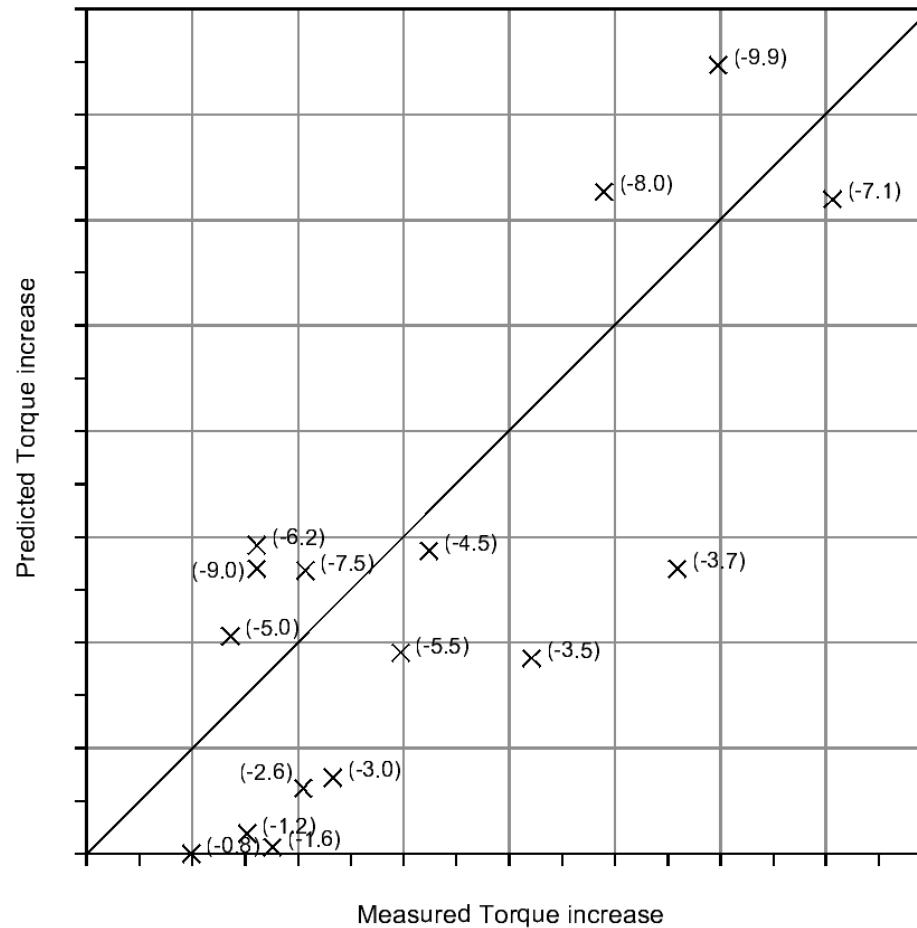


N-S simulation of beak ice

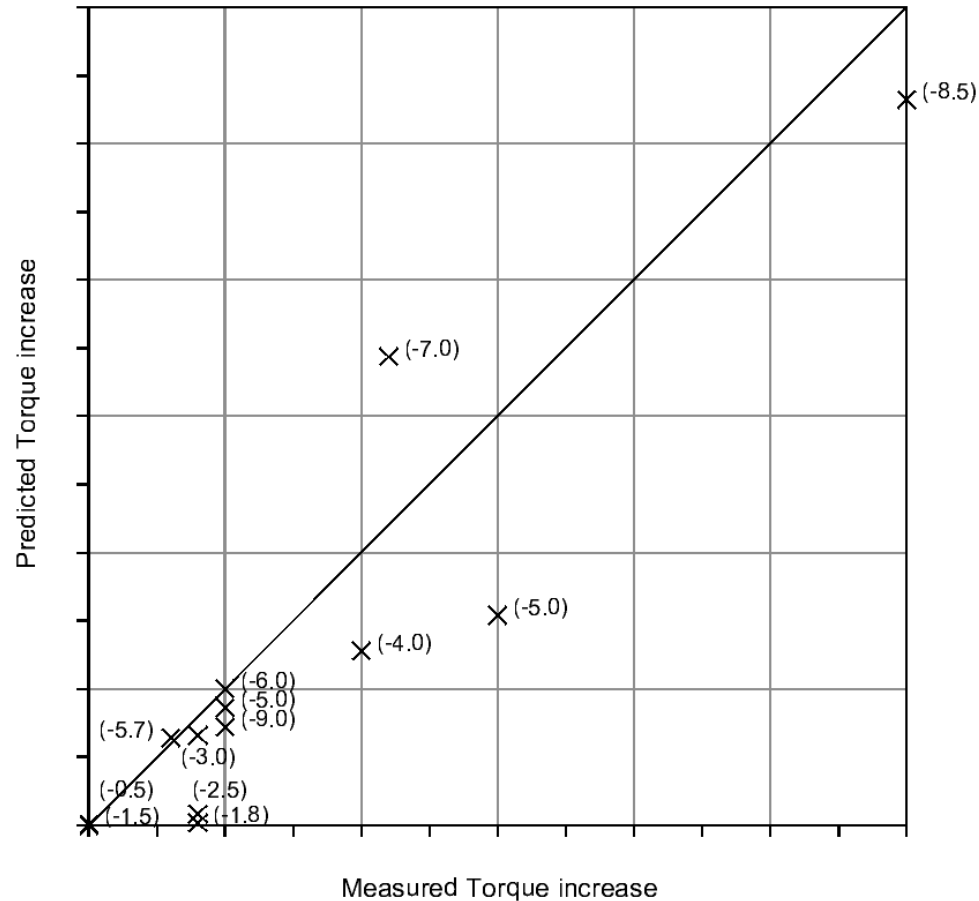
Rotor Performance in Icing Conditions



Rotor Torque Increment on Puma : Flight Test vs Prediction



Rotor Torque Increment on EH101 : Flight Test vs Prediction



Conclusions

- Modelling methods are mature enough to support design and development processes
- Predictive modelling now has potential to reduce requirement for flight trials and to enhance confidence in clearance
- Analysis can be used to support structural airworthiness assessments

Future Steps

- Further validation of blade accretion predictions, particularly ice shape
- Refinement of convective heat transfer modelling
- Advancement in CFD methods applicable to iced aerofoils
- Establishment of a flight trials data base for model validation
- Review with certification agencies of the role of rotor analysis

Acknowledgments

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Questions?